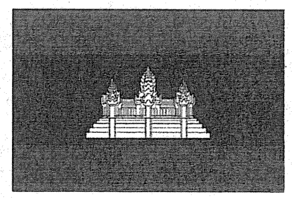

Integrating GIS in Public Health in the Kingdom of Cambodia

Prepared by Philip AbdelMalik
For Dr. David Zakus
International Health
University of Toronto

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Introduction

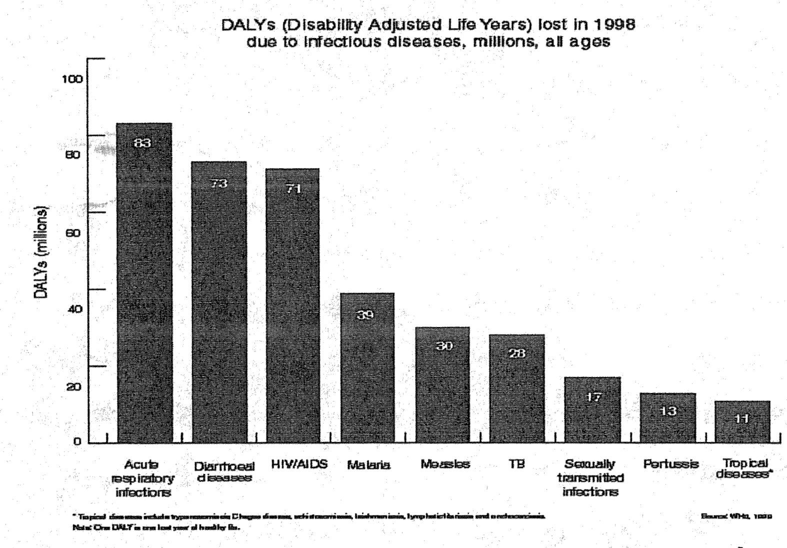
The study of population health forms the core of the realm of epidemiology,[1,2] which in turn is based on three fundamental components: person, time and place.[3] All events, whether on an individual or population level, occur in time and space, and must therefore be analyzed accordingly. Historically, epidemiology has focused primarily on the temporal dimension, only occasionally graced with that of space. With ever-improving technology, however, the importance of an integration of the spatial dimension is becoming more recognized, and also more accessible. More and more, epidemiologists and researchers worldwide are coming to realize the importance of this third parameter, so fundamental to population health, yet so often overlooked. It is no wonder, therefore, that geographic information systems are becoming a standard tool around the world, in every field.[4] Part I of this report sets the scene by painting a grand picture of the relationship between infectious disease morbidity and mortality and poverty in developing nations around the globe, and introduces the technology that is GIS. Part II then focuses this picture on the Kingdom of Cambodia, its population health status, and economy, to investigate the usefulness and feasibility of implementing a GIS infrastructure for public health, and argue in favour of the immediate and prolonged benefits of such an implementation in Cambodia. Finally, to further support the goal of promoting the implementation of GIS in public health, in Cambodia, a third section is included; Part III – included as a supplement with an accompanying CD - provides the opportunity for visual and practical hands-on usage of GIS, with boundary files specific to the Kingdom of Cambodia.

PART I

Infectious Diseases & Poverty

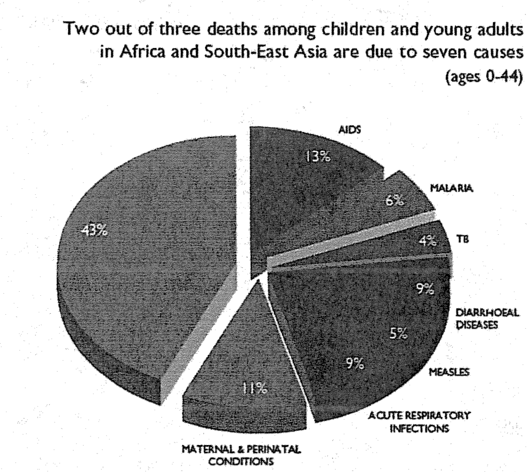
While the impact of chronic illnesses and injuries is recognized as a contributor to morbidity and mortality around the globe, and an important component of population health, this report focuses on infectious diseases in particular. This is primarily because these arguably constitute the heaviest economic and health burdens in developing nations. While the complex relationship between poverty and health will not be directly discussed in this report, it can be said that poverty, breeds infection…and infection breeds poverty.[7] Accounting for almost 50% of all deaths in low-income nations,[8] infectious diseases entangle their victims in a vicious circle of poverty and disease. Individuals cannot function in society, contribute to the economy or look after their families if they are rendered helpless by these diseases; instead, they become a burden to all three. As indicated in Figure 1, in 1998, infectious diseases alone accounted for a loss of 365 million disability adjusted life years. The economic impact of these years of life lost amounts to billions of dollars each year, representing a significant percentage of the national

Figure 1: Burden of Disease



Source: Removing Obstacles to Healthy Development, 1999 *WHO* Report[5]

Figure 2: Mortality in developing countries



Source: Health: A Key to Prosperity, 2000 *WHO* Report[6]

incomes of developing nations. Losses in national income mean a lower GDP, and a decline in economy. In fact, the top six infectious diseases in Figure 1 account for over 90% of deaths due to infections,[5] and almost 67% of all-cause mortality in Africa and South-East Asia[6] (see Figure 2). Yet each can be avoided with the use of existing, affordable interventions.[6] Ninety-nine percent of infant deaths caused by pneumonia, the deadliest of the acute respiratory infections, occur in developing countries while in developed nations, inexpensive antibiotics ensure treatment and survival. Nearly 2 million children under age 5 die each year from diarrhoeal diseases, almost all of which can be prevented with inexpensive saline solutions. Bednets and treatment strategies for malaria and tuberculosis, measles vaccinations and HIV sex education are all inexpensive solutions that are readily available and already implemented in developed nations. Yet millions die every year because of their absence.[5,6] Two of these diseases – tuberculosis and malaria – are briefly described below from a global perspective, not only because they exemplify the relationship between poverty and infection, but also because of their relevance to the Kingdom of Cambodia, their ease of treatment, and their existing application in GIS integration.

While HIV/AIDS, malaria and TB form the triad of most devastating illnesses ailing developing nations, only the two latter diseases are briefly described. Although HIV/AIDS is the single-most devastating disease of the triad, it is not described because it has received much more publicity and is much more prominent in the public consciousness; ask anyone what the current most devastating disease in developing nations is, and you're likely to hear of World Vision and other ads depicting AIDS as that disease; for this section, therefore, the purpose is to attempt to provide increased awareness of the devastating effects of the less frequently "advertised" malaria and TB; in addition, the prevalence of HIV/AIDS in Cambodia is low, at about 2.7% of the population,[9,10] and the discussed diseases therefore pose a greater overall, current threat, especially when occurring concurrently with AIDS.[11] It is recognized, however, that this does not detract from the severity of HIV/AIDS, or the reality and severity of potential spread. However, the GIS concepts discussed in this report are not limited to any particular disease

Tuberculosis

As one of the leading infectious disease causes of adult mortality and perhaps the most crippling to today's economies, the current global prevalence of tuberculosis (TB) stands at a staggering

one third of the population.[12] Each day, more than 23,000 people develop active tuberculosis and close to 5,000 die from the disease; translating this into annual figures gives roughly 8.7 million new cases of TB and an estimated 1.7 million deaths.[12] Without the expansion of current control initiatives, it is estimated that TB will kill more than 40 million people over the next 25 years, accelerated by the HIV/AIDS epidemic.[12] In 1996, it was estimated that about 11 million of the TB cases were in their most economically productive years of life.[13]

Tuberculosis has been described as a disease of poverty that ensnares its victims in a vicious cycle that exemplifies the poverty-health relationship. Over 90 per cent of TB cases and deaths occur in low and lower-middle income countries; the estimated economic cost to poor households exceeds US$ 12 billion per year. Usually, TB will end up killing the main wage-earner in a household, which in turn results in long-term debt and destitution for the whole family. ~~However~~ On the other hand, TB patients who survive are less productive than their healthy counterparts, and as a consequence end up losing roughly 20 to 30 per cent of their annual income. "Thus does a vicious cycle of poverty and TB prevail: poverty increases the risk of TB, and TB impoverishes its victims."[12] Yet curing TB is cheaper than economic investment in expensive ventilation systems or ultraviolet lighting schemes, both of which have been proposed and considered as prevention strategies.[13] Ultimately, TB control is itself an "investment in human productivity and economic performance, not a drain on the economy."[13]

Malaria

Malaria and poverty have also been shown to be intimately connected, reducing national income levels down to roughly one-third of nations without the disease.[14] The cost in work days lost is tremendous. Malaria presents a good example of a largely one-way economic relationship. The high levels of malaria on poor countries are not so much a consequence of poverty as they are of geographic location.[14,15] The ecologic conditions specific to each region determine the difficulty of eradicating the disease, depending on the environment's suitability for the survival of the mosquito vector. However, as shown in Figure 1, malaria has profound impact on the economy and poverty. Countries that have managed to eliminate malaria have experienced substantially higher economic growth than neighbouring countries; in fact, roughly 0.3% economic growth was observed for every 10% reduction in malaria.[14]

The usefulness of GIS in public health

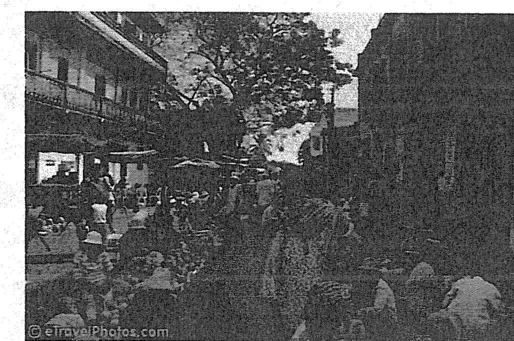
It has been said that better information leads to better decisions, however in order to get that information, one must ask the right questions, and in order to ask the right questions one needs the right set of tools.[16] GIS is a collection of items that together function as a system for converting data into information – much like the purpose of surveillance and data analysis. It is not GPS, nor is it a series of static maps or software packages. Simply put, a GIS combines layers of information about a place to give a better understanding of that place. What layers of information are combined depends on the purpose — be it finding the best location for a new store, analyzing environmental damage, viewing similar crimes in a city to detect a pattern, surveying the incidence and spread of a disease, or whatever the case may be. In a sense, it is akin to a series of overlaid, sophisticated and interactive report maps, where each set of features comprises a thematic layer. Information about these themes (e.g., where points are located, how long a road or river is, how many square miles a lake occupies, etc) is also stored in binary digital format as a series of ones and zeros in a thematically-associated database. Themes are overlaid, one on top of the other, creating a stack of information about the same geographic area. Individual themes can be manipulated and turned on and off at will, thereby controlling the amount of information depicted.

One may ask, however, what the added benefit of using GIS in public health is over complex, spatial statistical analyses? The old adage, "a picture is worth a thousand words" immediately comes to mind, and this is precisely what GIS does to health data – paint a picture. In epidemiology, one is dealing with population health, and population has a location. Any health event, whether looking at cases within a population, or comparing two different populations, always exists in space and time, with important spatial demographic data. These include data on socioeconomic status, which can be approximated by neighbourhoods in which individuals live; proximity to water, or ~~in the case of~~ one of the "fathers" of epidemiology, John Snow, proximity to certain water pumps. One can also bring together additional data – such as atmospheric or meteorological data – that may have relevance to the event under study – for example rainfall, season and malaria outbreaks. The produced maps can also simply be used to get a preliminary and very quick picture of the event under investigation, which may then provide clues about how to proceed. This is the principle behind incident analysis, where spatial distribution of incidents

indicates whether or not there are hotspots one should be focusing on. In addition, complex algorithms can and have been implemented for the detection and prediction of possible outbreaks, through tempero-spatial early warning systems.[17,18] This is especially effective if one animates the spatial data over time.

PART II

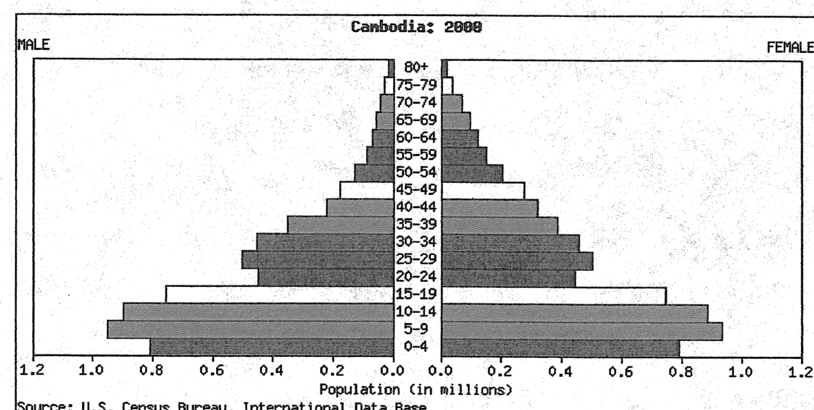
The Kingdom of Cambodia: Economy and Population Health



Street Market in Cambodia
Source: eTravelPhotos.com[19]

Nestled between Thailand and Vietnam, South of Laos, the Kingdom of Cambodia is home to over 13 million inhabitants,[21] of whom over 40% are under the age of 15 years.[20] The population pyramid for the year 2000, shown below in Figure 3, is characteristic of a developing nation, with a broad base signifying the disproportional composition of younger children, and a narrow peak representative of the low life expectancy (males 52y, females 55y).[22] In 1998, the National Institute of Public Health in Cambodia reported the top three causes of hospitalization in the country to be Acute Respiratory Illnesses (8.78%), Tuberculosis (10.02%) and Malaria (13.00%), with the largest proportion of hospital mortality being attributed to malaria (19.15%).[23] Interestingly, HIV/AIDS was not on their list, likely because it has a low incidence rate in the Kingdom (prevalence rates are higher than incidence rates, and for the Kingdom of Cambodia, AIDS prevalence is estimated at around 2.7%).[9,10] Roughly one third of the Kingdom's gross domestic product (GDP) is agricultural, and the gross national income (GNI) per capita is around US$270 (compared to Canada's US$21,340).[21] The Kingdom's human development index (HDI), which measures human development by combining life expectancy at birth, adult literacy and mean years of schooling, and income, places it 130th out of 173 countries, and only about 30% of the total population has reasonable access to an adequate amount of drinking water from improved sources.[21] Clearly, the developing Kingdom of

Figure 3: Population Pyramid, Cambodia, 2000[20]



Cambodia is plagued with the vicious cycle of poverty and ill-health, and the implementation of a GIS infrastructure for public health must be demonstrably beneficial and extremely cost-effective.

The benefits of implementing a GIS Infrastructure in Public Health – Learning from other Nations

GIS applications relevant to this report and the diseases previously discussed have been implemented in several developed and developing nations. For example, GIS has been used in Germany to investigate the spatial patterns of tuberculosis incidence,[24] whereas New York has implemented a Dynamic Continuous-Area Space-Time System (NY-DyCAST) for West Nile surveillance.[17] While this second example may not seem immediately relevant, it is mentioned here because of the similarity West Nile shares with malaria – the mosquito vector. Although different species are responsible for the transmission of the two diseases, using such similar examples can serve as a model for and enhance the development of appropriate malaria GIS systems. In the New York system, a localized Knox test allows for statistical testing of interaction between space and time of disease incidence, calculated by pairing all possible data points (e.g. location in space and time of bird deaths) within a clearly defined geographic area and temporal window (in this case, 2.41 km area, 21-day moving window) and testing against assigned values of what would be considered "close" in space and time. This is then compared to the expected for no space-time interaction, and a probability of non-random space-time interaction is determined. When the p-value is less than the desired alpha level, typically 0.05, the likelihood of space-time interaction is significant. The model creates a surface of probabilities per cell, for a grid of 1,400 cells overlaying NY city, and each cell is assigned a Knox probability based on an analysis of dead birds within a 2.41 km radius of the cell's centroid. Using this model in 2001, the city of New York correctly identified 5 of 7 areas of high WNV risk at least 13 days prior to illness onset. While not without its limitations and assumptions, the NY-DyCAST technique can serve as a model for future GIS development.

GIS development in the health sector has also been ongoing in developing nations, particularly for malaria surveillance in Africa, fuelled by support from large NGOs, such as the World Health Organization. These include the WHO's Roll Back Malaria program,[25] MARA (Mapping Malaria Risk in Africa),[26] and SAMC, the South Africa Malaria Control Program,[27] all of which

have developed and use GIS to monitor, track and predict malaria occurrences. This is a good example of the many unique layers, such as meteoroligcal data, that can be used in combination with public health surveillance to increase knowledge and aid in the decision making process. It is difficult, for example, to link rainfall with mosquito breeding habits and densities without using GIS, but when done, for example in South Africa for 2002-03,[28] it resulted in the detection and forecasting of early and increased transmission due to consistent rainfall and early temperature drops, allowing appropriate response measures to be taken. This led the Southern Africa Malaria Control program to endorse the collaboration of meteorologists and health professionals in fighting malaria.[27] Cambodia's neighbour, Thailand, has also used GIS to investigate the relationship between malaria and vegetation cover.[29] While the results were inconclusive, this is nonetheless a positive step in the integration of GIS in the health sector, and points to the possibilities for enhancing ~~disease transmission for~~ control and prevention. of disease transmission.

The requirements, costs and feasibility of implementing a GIS-public health infrastructure in Cambodia

GIS Requirements

Geographic information systems are comprised of four basic components: hardware, software, data and the user. An assessment of the availability and usability of each of these in the Kingdom of Cambodia is the first step in determining the feasibility of GIS integration in the public health sector.

It is likely obvious what kind of hardware is required for a GIS; a computer with a powerful graphics card and ample memory is ideal, since the map drawing aspect is graphics intensive and dependant on the layer detail. For example, drawing of extensive road or sewer networks demands more processing power and memory. In addition, temporal analysis using map animation over time requires sufficient memory and resources. If one intends to print the maps, a printer is required– probably a colour one – or even better, a plotter which will allow one to print out wall-size maps. With advances in technology, one can even use handhelds to carry out some primitive GIS functions with simpler layers. GPS units are useful for identifying event locations, for later transfer to the GIS database. An Internet connection is also extremely useful for everything from collaboration to downloading boundary files and satellite images that can be used for GIS applications. Acquiring the necessary hardware in Cambodia is perhaps the

simplest and cheapest of the four components. Computers are widely available, and cost is relatively cheap (a complete system at 1.3 GHz and 256 Mb RAM can cost under $400).[30] Furthermore, although still slow by developed nation standards, internet usage and availability has steadily increased over the past few years, with prices being driven lower by increasing internet service provider competition.[31] DSL Broadband service, for example, though still expensive, is nonetheless available and offered in select locations, ranging in price from $99 to $6,000 per month.[32,33] While useful, this is not a necessary on-site component of GIS.

GIS software provides the tools needed to store, manipulate, analyze, and present information about places and events. There are a few important things to look for in GIS software, particularly a database management system, tools that allow you to query the maps and a friendly graphical user interface. There are a variety of GIS software packages available on the market, ranging in cost from free to several thousands of dollars. The CD provided with this report contains two free GIS software applications: ESRI's ArcExplorer 2.0, which provides basic GIS functions, and SPRING 4.0 from the National Institute for Space Research in Brazil. SPRING 4.0 is a complete GIS application, available in an English interface; however due to the fact that most of the documentation is currently in Spanish, the learning requirements are somewhat specific! Nonetheless, the availability of the application provides an extremely cost-efficient (free!) software component of the GIS, requiring only perhaps slightly more time to learn if the user is non-Spanish speaking. There are several other "open source software" initiatives in South-East Asia which provide a promising cost-efficient GIS software component.[34]

Data for use in a GIS comes in a whole range of shapes and sizes. As far as the geography – or boundary data – is concerned, it can range from standard map and graphics file formats and images to CAD files, whereas event data can be in spreadsheets, relational databases, statistical software, and so on. The geography - or boundary - files can be the most costly component of the GIS (particularly in developed countries), although depending on the type of data required, they may sometimes be obtained for free. In the case of Cambodia, acquiring the geography data may prove to be easier than other places due to the development of the Digital Asia Network (DAN), discussed below. In addition, the author of this report conducted an extensive search on the Internet in an attempt to provide free boundary files for Cambodia, and met with some success!

The fruits of his labour are provided in the accompanying CD, and references provided in Part III. As for health data, this can either be acquired with the use of GPS units, hospital data, or, as already implemented in 1998 in Cambodia, a national health survey.[23]

Last, but not least, personnel are required to operate the GIS. Training will depend on the complexity of analysis required, however extensive existing collaborative efforts and the previously mentioned Digital Asia Network are both facilitators of this critical component. In addition, with the increasing realization of the usefulness of GIS in public health, more epidemiologists are developing an interest in the field (the author being one example!) thereby increasing the pool of qualified personnel who can then either train others or participate more directly themselves.

The Digital Asia Network (DAN)

DAN is a three-year initiative proposed in 2002, aimed at providing "people and communities with easy access to geo-spatial information over the Internet, through open sharing of GIS and Remote Sensing Data among all the countries of Asia".[35] The network's main objectives centre around the sharing of geo-spatial information and stimulate the development of GIS application in the region. Unfortunately, the health sector is not represented in their list of target uses – proposing this addition would be a positive and supportive step for participation in and the continued implementation of the network. The project has had support and funding from the National Space Development Agency of Japan, and has been acknowledged by the Working Group for Information Systems and Services (WGISS).[36] Perhaps with increasing promotion of GIS integration in the health sector, other organizations such as UNESCO and the WHO would contribute to this beneficial network.

Issues, Barriers & Considerations

In implementing any system, the potential obstacles must be considered and addressed. The most obvious and immediate barrier to the implementation of a GIS in Cambodia is the training required. Literature suggests the cost of training to be between 30% and 40% of the total cost of GIS programs,[37,38] not to mention the potential language barrier. To address the latter issue, one may want to consider a commercial (therefore more expensive) software application, such as IDRISI or ArcGIS, because of their availability in various languages, ease of use, global experience and availability of price discounts for research, academic and other non-profit use.[39]

Furthermore, once events are mapped, data needs to be converted to information, used to further knowledge and produce results. This requires training in statistical analyses and data interpretation, possibly using additional applications such as SPSS or SAS (which, incidentally, is compatible with ArcGIS). Another obstacle, mentioned earlier, is the acquisition of digital geography – the boundary files. Paper maps, the most likely form of geography available, can be scanned into more sophisticated GIS applications, and "digitized". However, this requires additional hardware, time and training. Unfortunately, for downloaded data, there is no international standard format, which hinders data sharing and collaboration.[37] Legal issues may also arise from questions about geography and data ownership, and the ethics surrounding confidentiality of patient information – mapping of events requires certain demographic information, which may be as anonymous as the province in which the patient was seen, down to the patient's exact address. Therefore, legislation must be implemented to provide for the various possible scenarios.

Conclusions

No doubt the implementation of any program in any nation, be it developed or developing, will have its share of obstacles and barriers. However, the critical question to address is whether the benefits ultimately outweigh the costs, and in the case of the integration of GIS in public health, the literature and increasing use of GIS suggests this to be the case. It is clear that the implementation of GIS in the public health sector of developing nations is not a new or unrealistic concept, and that its potential for aiding in public health surveillance and improvement has not only been recognized, but also continues to be developed. In the case of developing nations, and Cambodia in particular, the toll of infectious diseases on the population is extremely high, which in turn nourishes a vicious cycle of ill health and poverty, crippling the nation's economy. A GIS would not only help the urban planning and development of the nation, but also help improve the population health, revealing spatial patterns of morbidity and mortality, and helping predict areas of potential outbreaks, thereby facilitating early prevention and control planning. This has proven to be true in developed and developing nations alike, for illnesses identical to those plaguing Cambodia. The technology exists, and is readily available, aided by international and regional efforts. All that remains is that the obstacles be addressed, and the project be undertaken and implemented.

PART III

Accompanying CD Contents

The CD accompanying this report was put together by the author as an example of the availability and usability of Cambodia-related data. Many hours were spent searching the web for appropriate boundary files, which were then used to build a project in ESRI's ArcExplorer application. The CD contents are as follows:

ESRI ArcExplorer 2.0

PATH: CD:\Cambodia GIS\GIS Programs\ESRI ArcExplorer

This is a basic but free application from ESRI, capable of performing simple queries. ArcExplorer allows one to display and query a wide variety of data sources, including industry-standard ESRI shapefiles, ArcInfo coverages, and ArcSDE (Spatial Database Engine) layers. The application allows one to pan and zoom through multiple map layers and identify, locate, and query geographic and attribute data, and even perform basic statistical analysis on the geographic data. ESRI allows the free distribution of this application.[40] Documentation and an import module are also included.

A project using some boundary files for the Kingdom of Cambodia was built using this application, and can also be found on the CD. The ArcExplorer application must be installed for the project to be viewed.

INPE SPRING 4.0 from the National Institute for Space Research in Brazil

PATH: CD:\Cambodia GIS\GIS Programs\National Institute for Space Research, Brazil

SPRING is a "state-of-the-art GIS and remote sensing image processing system with an object-oriented data model which provides for the integration of raster and vector data representations in a single environment." The applications was produced by the National Institute for Space Research (INPE) in Brazil, with assistance from various other organizations.[41] Unfortunately, most of the documentation is in Spanish, and time did not allow for the learning required to develop a project in this application. However, it is included because it is a free and complete GIS application, with the hope that its potential use will be investigated.

Boundary Files – Cambodia

PATH: CD:\Cambodia GIS\Boundaries

The following geographies are included on the CD. Please note that they are not all ready for use; some are zipped, and require unzipping; others are in E00 format, and need to be imported using the import tool, import71.exe, found in the same directory as the ESRI ArcExplorer application.

Source: Digital Chart of the World Data Server[42]
PATH: CD:\Cambodia GIS\Boundaries\DCW

Geographies:

Political/Ocean (Point)
Populated Places (Polygon)
Populated Places (Point)
Rail Roads (Line)
Roads (Line)
Utilities (Line)
Drainage (Network)
Drainage (Point)
Drainage Supplememtal (Point)
Hypsography (Network)
Hypsography (Point)
Hypsography Supplememtal (Line)
Hypsography Supplememtal (Point)
Land Cover (Polygon)
Land Cover (Point)
Ocean Features (Line)
Ocean Features (Point)
Physiography (Line)
Aeronautical (Point)
Cultral Landmarks (Point)
Transportation Structure (Line)

Source: ESRI Web site[40]
PATH: CD:\Cambodia GIS\Boundaries\ESRI Data

Geographies:

Country Boundaries (Data and Maps)
Water Bodies (ArcWorld)
Major Rivers (ArcWorld)
Major Highways (ArcAtlas)
Boundary Lines (ArcWorld)
Major Cities (ArcWorld)

Source: United Nations Environment Program[43]
PATH: CD:\Cambodia GIS\Boundaries\UNEP

Geographies:

South East Asia Administrative Boundaries
South East Asia Population Density

Source: NASA Earth Observing System Data and Information System[44]
PATH: CD:\Cambodia GIS\Boundaries\LP DAAC

Geographies:

Global forest cover (note: this is a zipped image, which, when unzipped, is over 500 Mb in size)

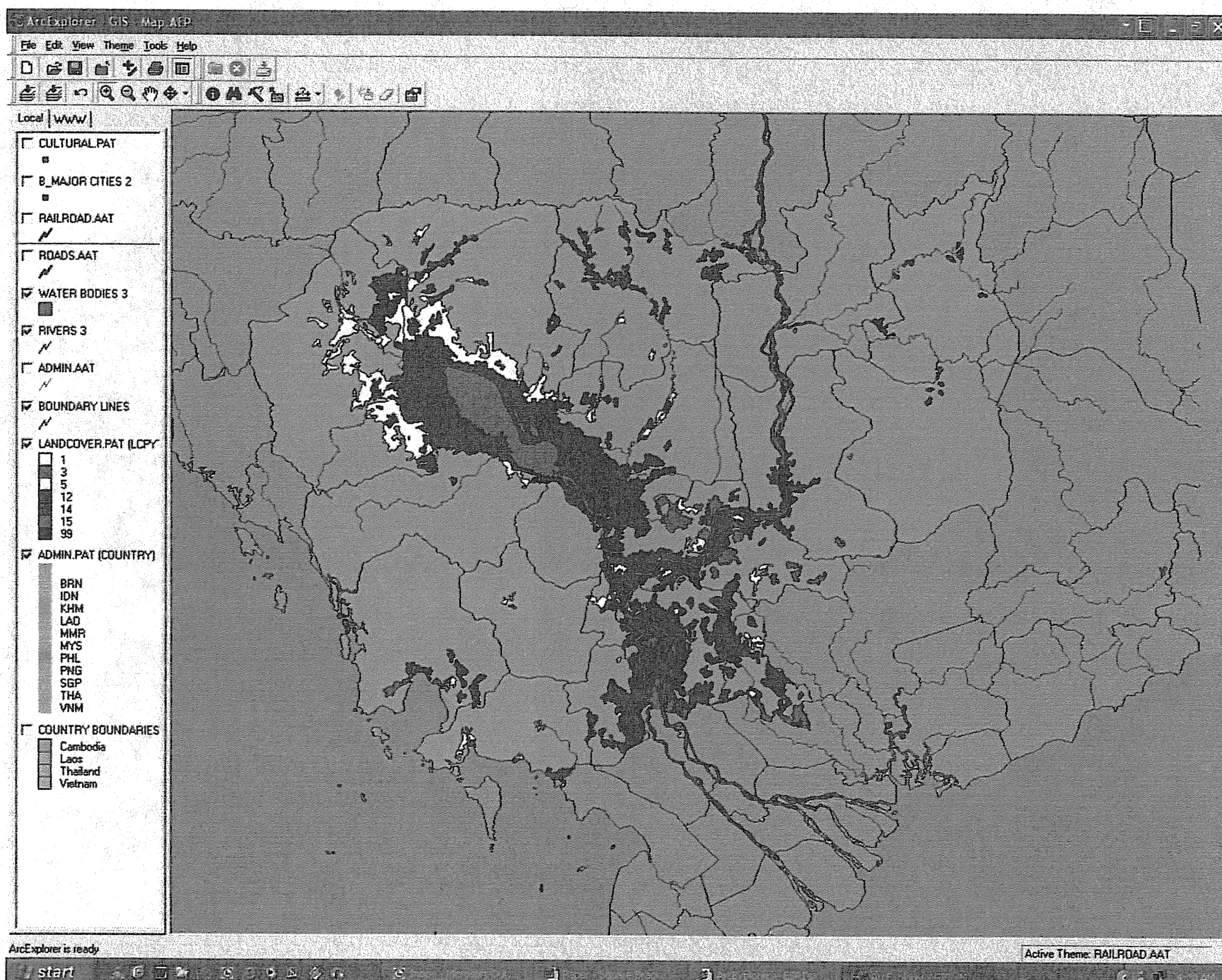
Cambodia ArcExplorer Project File

PATH: CD:\Cambodia GIS\Project

This project, built in ArcExplorer, contains selected layers as shown in Figure 4. Layers may be turned on or off, and additional layers may also be added. Note that for land cover (taken form the Digital Chart of the World), the following key is required:

1	Rice Field	14	Inundated area
3	Cultivated area / garden	15	Undifferentiated wetland
5	Salt pan	99	Unspecified / unknown
12	Unconsolidated material		

Figure 4: Screen shot of ESRI's free tool, ArcExplorer, displaying selected Cambodia themes



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